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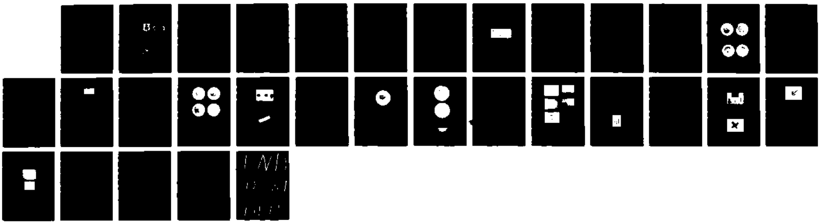

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THE MECHANISM OF ELECTRICAL EROSION OF METALS

by

S.L. Mandel'shtam, S.M. Rayskiy

FOREIGN TECHNOLOGY DIVISION

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П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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THE MECHANISM OF ELECTRICAL EROSION OF METALS*

S. L. Mandel'shtam and S. M. Rayskiy

1. Introduction

In certain forms of electrical discharge, in a condensed spark discharge, in particular, as we know, severe damage occurs to both electrodes or one of them. This phenomenon, which has been given the name "electrical erosion," plays an extremely harmful role in a number of practical applications of the discharge. It results in intense damage to high-voltage switches, relay contacts, sparkplugs of internal combustion engines and other discharge devices. At the same time, this phenomenon has come into extensive use recently for machining metals. A new, more highly effective method for cutting, drilling and other machining of metals, which was proposed by B. R. Lazarenko and has come to be called the "electric spark

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method," has been constructed based on the use of this phenomenon. Considerable literature has been devoted to the phenomenon of electrical erosion. The results of this research have been summarized partially in well-known works of B. R. Lazarenko and N. I. Lazarenko [1] and a monograph by Holm [2]. An extremely large body of material characterizing the influence of parameters of the discharge loop, properties of the medium and other factors on the magnitude of erosion of a material and the form of the electrodes has been accumulated. A whole series of semiempirical quantitative rules have been obtained. Despite the practical importance and physical interest represented by the phenomenon of "electrical erosion," the physical mechanism of this phenomenon still remains unexplained. Some researchers are inclined to attribute a primary role in the phenomenon directly to processes of thermal vaporization of the electrode metal [3], while others lean toward processes of electrolysis; the hypothesis of the effect of electrodynamic forces and a number of other surmises are also expressed.

The phenomenon of electrical erosion undoubtedly is an extremely complex process, in which the factors listed above participate to some extent. It seems to us, however, that the basic phenomena of electrical erosion find a free explanation from the point of view of a simple physical representation of the mechanism of the phenomenon, to which, as far as we know, no attention has been devoted until now. In this process we started based on the following considerations. Examination of existing material indicates that the phenomenon of electrical erosion is most sharply pronounced in a high-voltage condensed spark discharge and in a lower voltage arc discharge in shunting of the arc by a large capacitance (an arc "in a spark mode").

In a high-voltage spark discharge of a capacitor, most of the energy stored on the capacitor is released, as we know, in the so-called arc stage of the discharge. This stage occurs at a voltage on the discharge of the order of a few tens of volts and a current force which reaches hundreds or thousands of amperes, depending on the discharge parameters. By reducing the voltage level to which the capacitor is charged and increasing the capacitance of the capacitor accordingly, one can obtain the same current force in a low-voltage arc discharge in a "spark mode" as in a high-voltage discharge.

Thus there apparently is no fundamental difference between high-voltage and low-voltage spark discharges from the point of view of electrical characteristics; the spectra of the two types of discharge are also similar [4]. Consequently, the specific nature of the spark discharge is not related to the magnitude of the initial voltage or the current force realized in the discharge. The fundamental difference of a spark discharge, high-voltage of low-voltage, from an arc discharge lies in the fact that the discharge channel does not manage any sharp expansion in a spark discharge due to the short duration of the current pulses [5]. Due to this fact, the current density in a spark discharge reaches high values, of the order of 10^5-10^6 A cm^{-2}, while it rarely exceeds 10^2-10^3 A cm^{-2} in an arc discharge. This property of a spark discharge accordingly conditions the specific features of the discharge channel, a high temperature, reaching 10,000-15,000°C, leading to excitation of "spark lines," and the specific features of the effect of the discharge on the electrode. These latter features result in the fact that the extremely great energy released from the electrode surfaces, due to the short discharge duration, does not manage to propagate for any distance in the metal. All this energy is passed on to a surface section of the metal which is very small in dimensions, which results in its explosive vaporization. It is well known from numerous studies of the spark discharge that the formation of electrode metal vapors occurs in the form of luminous streams of flares escaping perpendicular to the electrode surfaces at a velocity which reaches several thousand meters per second.

The trajectory of the flares can fail to coincide with the trajectory of the discharge channel. N. N. Sobolev [6] managed complete spatial separation of the flares and the channel and studied them. According to his data, the temperature of the flares reaches 10,000°C. Figure 1 shows photographs of a few characteristic types of flares.

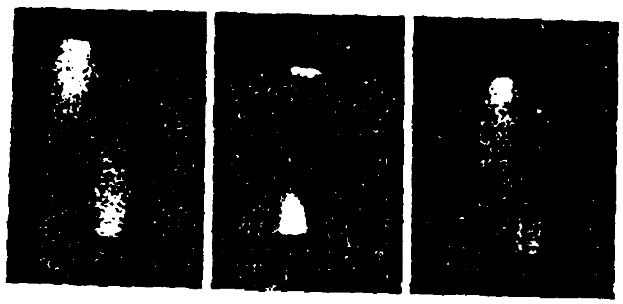

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Fig. 1. The form of flares in a capacitor discharge: a - the flares propagate perpendicular to the electrode surfaces; an oscillating discharge; b - bottom electrode, cathode; top electrode, anode; the flare from the cathode is stronger than the flare from the anode; c - bottom electrode, flat; top electrode, conical; the flare is stronger at the pointed electrode; oscillating discharge.

These properties of the flares - a high propagation velocity and an increased pressure, as will be demonstrated later - make the flares similar to explosive detonation products. It follows that these flares obviously should be capable of effecting destruction of obstacles which they encounter, primarily the opposite electrode.

And this destruction, from our point of view, is the main cause of erosion of the electrodes. Electrical erosion thus is not related directly to the electrical discharge but is a secondary process conditioned by the mechanical effect of jets of metal vapors caused by the discharge. This picture immediately finds confirmation in the next very characteristic feature of erosion phenomena - more severe damage of the anode than of the cathode; therefore, in particular, in the electric spark method in machining of metals, the workpiece is connected as the anode, and the tool is connected as the cathode. Actually it is well known from studies of flares that flares from the cathode are significantly more intense than flares from the anode [7] (see also Fig. 1, b). And this conditions more severe damage to the anode by the cathode flare as compared to damage to the cathode by the weaker anode flare.

It follows further from this picture that discharge conditions in which the flares are no longer capable of damaging the opposite electrode (a low current density, a great distance between electrodes) are possible. In this case, one must expect great damage to the cathode due to stronger formation of flares and partial depositing of the cathode flare material on the anode. Under such conditions, the magnitude of erosion obviously will be significantly less. This phenomenon of inversion of erosion is also well known. It was discovered and studied for the first time by B. R. Lazarenko and is exhibited in certain modes of operation of relay contacts [8].

2. Experimental Section

The hypotheses developed above concerning the mechanism of electrical erosion as a process conditioned by the mechanical effect of flares permits direct experimental verification:

a) the damage to both electrodes should decrease rapidly with an increase in the distance between electrodes;

b) screening of the flares preventing them from reaching the opposing electrode should also reduce the damage to this electrode;

c) the destructive effect of a flare on the opposing obstacle should be preserved in spatial separation of the discharge channel from the flare;

d) by creating conditions which promote obtaining more sharply defined flares, one can intensify their destructive effect. Further, by creating conditions which prevent rapid expansion of the flares, one can increase the distance from the origin of the flare at which it preserves its destructive effect.

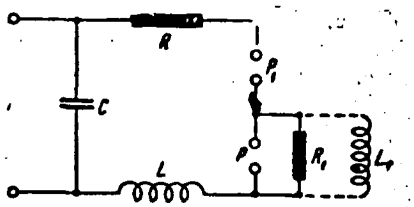

Fig. 2. Diagram of a stable loop with two sparks. The capacitance C is charged through a shunting resistance R_1 or a self-inductance L_1 up to breakdown of the stable regulated gap P_1. After the breakdown, the voltage is concentrated on the larger resistance R_1 (or L_1), which causes breakdown of the gap P under investigation.

The authors have performed these experiments. For convenience in experimentation, we used a high-voltage spark connected according to the scheme proposed by one of the authors

[9], which makes it possible to vary the length and other parameters of the spark gap without changing the magnitude of the energy realized in the spark. A spark diagram is shown in Fig. 2. The magnitude of the capacitance amounted to 1 μF; the initial voltage on the capacitor was 10 kV. For effecting an aperiodic mode, a resistance near the critical value ($\sim 5\Omega$) was included in the loop.

The Effect of the Distance Between Electrodes and the Sign of the Electrode on the Magnitude of Erosion

The first series of experiments studied the effect of the distance between electrodes and the sign of the electrodes on the magnitude of erosion. Steel balls from a ball bearing with a diameter of 10 mm served as electrodes. Selection of the electrodes was dictated by the following consideration. For avoiding an effect of the form of the electrode surface on the intensity of the flares and, consequently, on their destructive effect in establishing the role of the distance between electrodes and their sign, it was necessary to use electrodes of identical form with the proper surface area besides. Balls from a bearing are ideal electrodes from this point of view. It is also significant that damage shows up clearly on their polished surfaces.

Figure 3 presents photographs of electrodes with a short spark gap of 0.1 mm and 10,000 discharges. Figure 4 presents photographs of ball surfaces with a large spark gap - 4 mm - after 50,000 discharges. As one can see from the photographs, the magnitude of erosion with a large gap (Fig. 4) is significantly less than with a small gap (Fig. 3), despite the fact that the number of discharges with a large gap was significantly greater (50,000) than with a small gap (10,000). With a small gap, the anode (b) undergoes considerably more severe damage than the cathode (a). With a large gap, inversion of erosion occurs: the cathode (a) was damaged due to flare formation, while a projection of cathode material applied to the anode was formed on the anode (b) at the center. Similar results were obtained with copper and other electrodes.

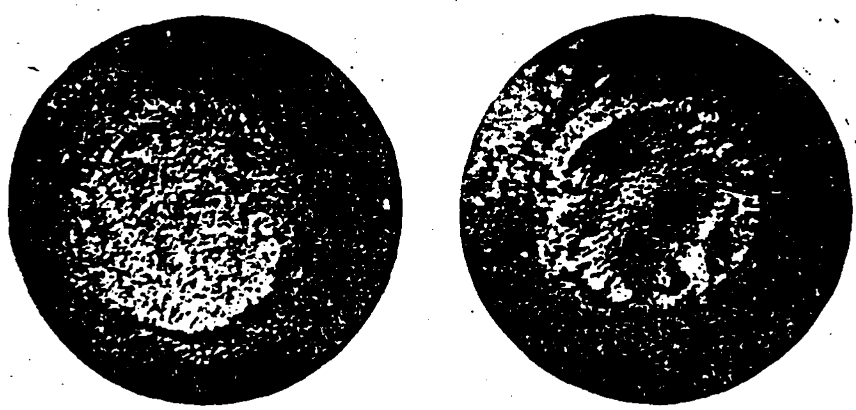

Fig. 3. Damage to steel ball electrodes at a short distance between them - 0.1 mm - after 10,000 discharges: a - cathode; b - anode.

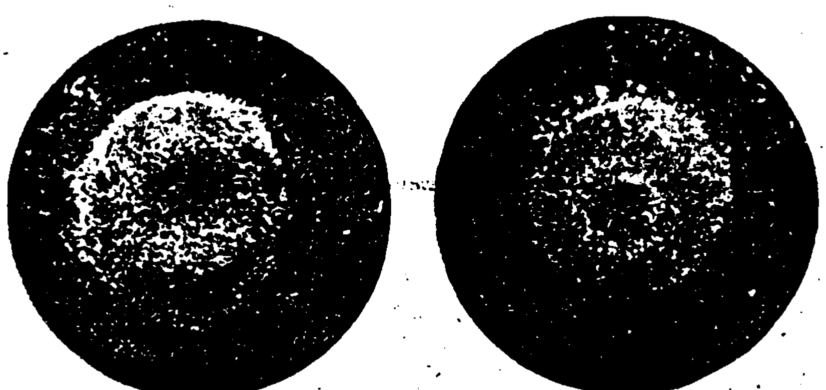

Fig. 4. Damage to steel ball electrodes at a large distance between them - 4 mm - after 50,000 discharges: a - cathode; b - anode.

The Effect of the Form and Material of the Electrodes on the Magnitude of Erosion

In our previous studies of the luminescence of flares in a spark discharge, an observation was made which was not published: the brightness of the flares, their length and the regularity of their form depend greatly on the form of the electrode surfaces. The use of a conical electrode ending in a point proves to be a necessary condition for obtaining sharply defined long and bright flares. Just before each experiment, the electrode must be carefully reground into a regular cone. It was established that the reason for the effect of the electrode shape does not lie in movement of the discharge over the electrode surface in a case where the electrode has no point but is related to features of flare formation on a pointed conical electrode. The difference between flare forms for conical and flat electrodes is clearly seen in Fig. 1, c. One should have expected the pointed conical electrode to produce intensification of the erosion effect on the opposite electrode. For establishing the influence of the flare form on the magnitude of erosion, an arrangement of electrodes shown in Fig. 5 was used. A copper electrode with a diameter of 4 mm in the cylindric part was attached to an insulator between two balls from a bearing. One end of the electrode was sharpened into a pointed cone, while the other had a spherical surface. The distances from the point of the cone to a ball and from the spherical end to the other ball are equal. This arrangement of electrodes provides the possibility of reliable comparison of the effects of pointed conical and blunt surface shapes. The damage caused by a pointed conical electrode proved considerably greater than the damage caused by a blunt electrode.

Then we studied the effect of the electrode material creating the flare. We tested a number of metals: iron, aluminum, magnesium and copper. Copper proved to cause the

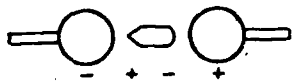

Fig. 5. Diagram of the arrangement of electrodes for determining the influence of their form on the magnitude of erosion.

greatest damage to the opposing electrode. Together with I. S. Abramson, we took sequence photographs of the development of a discharge between two conical electrodes. An exposure of the order of $1 \cdot 10^{-6}$ s made it possible to trace the dynamics of flare form variation. Flares from copper electrodes proved to possess greater compactness and stability than flares of the other metals tested. This feature of copper flares explains the greater capacity of copper for damaging the opposing electrode than the other metals. The photographs shown in Fig. 6 illustrate what has been said: a - the photograph shows a discharge between copper electrodes; b - a discharge between magnesium electrodes. The bottom electrodes served as the cathode in both photographs, while the top electrodes were the anode. The greater compactness and stability of flares in the case of copper as compared to flares in the case of magnesium can be seen clearly in these photographs.

Further experiments served for verifying the role of the distance in the mechanism of electrical erosion, but now they were performed with pointed conical copper electrodes as flare sources. Figure 7 shows diagrams of the arrangement of electrodes: a) at great distances; b) at short distances; c) with a combination of short and long distances. This arrangement of electrodes also provides the possibility of reliable comparison of experimental results. Figure 8 presents photographs illustrating the role of the size of the gap between

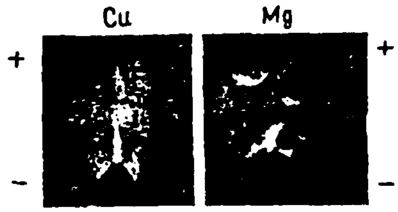

Fig. 6. The effect of the electrode material on the size of the flares: Cu - copper electrodes; Mg - magnesium electrodes; the bottom electrodes are the cathode, and the top electrodes are the anode. The flares are stronger in the case of copper electrodes.

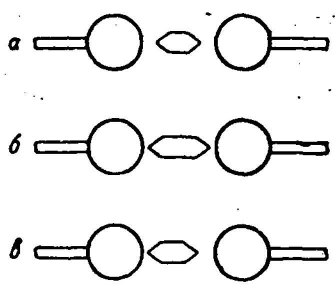

Fig. 7. Diagram of the arrangement of electrodes in experiments with the influence of the distance between pointed conical copper electrodes on the magnitude of erosion: a - steel balls at a great distance from the electrodes; b - steel balls at a short distance from the electrodes; c - one steel ball at a short distance from an electrode, and another ball at a long distance.

electrodes on the magnitude of erosion: a) a ball at a distance of 0.3 mm from the point of a cone which serves as the cathode; b) a ball at a distance of 0.3 mm from the point of a cone which served as the anode; c) a ball at a distance of 4 mm from the point of a cone which served as the anode; d) a ball at a distance of 4 mm from the point of a cone which served as the cathode. Under these conditions, the role of the sign of the electrode is not of decisive importance, while the role of the distance between electrodes, on the contrary, is very great. Deep craters formed on the balls are visible with a very short spark gap, while shallow surface damage in the form of pitting and metal droplets can be seen at large distances of the ball from the point of the cone. The number of discharges was 300 in both cases. Damage thus is intensified as before with a decrease in the size of the gap. An extreme intensification of the effect of erosion itself from pointed conical electrodes as compared to spherical electrodes as a flare source is also observed. For example, damage produced by a pointed cone at 300 discharges exceeds damage produced by spherical electrodes at 10,000 discharges. As a measure of the destructive effect of a pointed conical copper electrode connected as the cathode, its effect on a thin steel plate located at a distance of 0.1 to 0.3 mm was tested. A steel plate with a thickness of 0.1 mm (a razor blade) proved to be pierced at the first or second discharge under these conditions.

Figure 9 presents photographs of three such sequential discharges: a - first discharge; b - second discharge; c - third discharge. A pointed conical electrode is placed vertically, while the plate is positioned horizontally. The luminescence of vapors under the plate can be seen in the photograph in the very first discharge; this indicates that the plate has been pierced. Unique showers, the tracks of luminous dust from the plate escaping in its destruction, are clearly visible in photographs b and c.

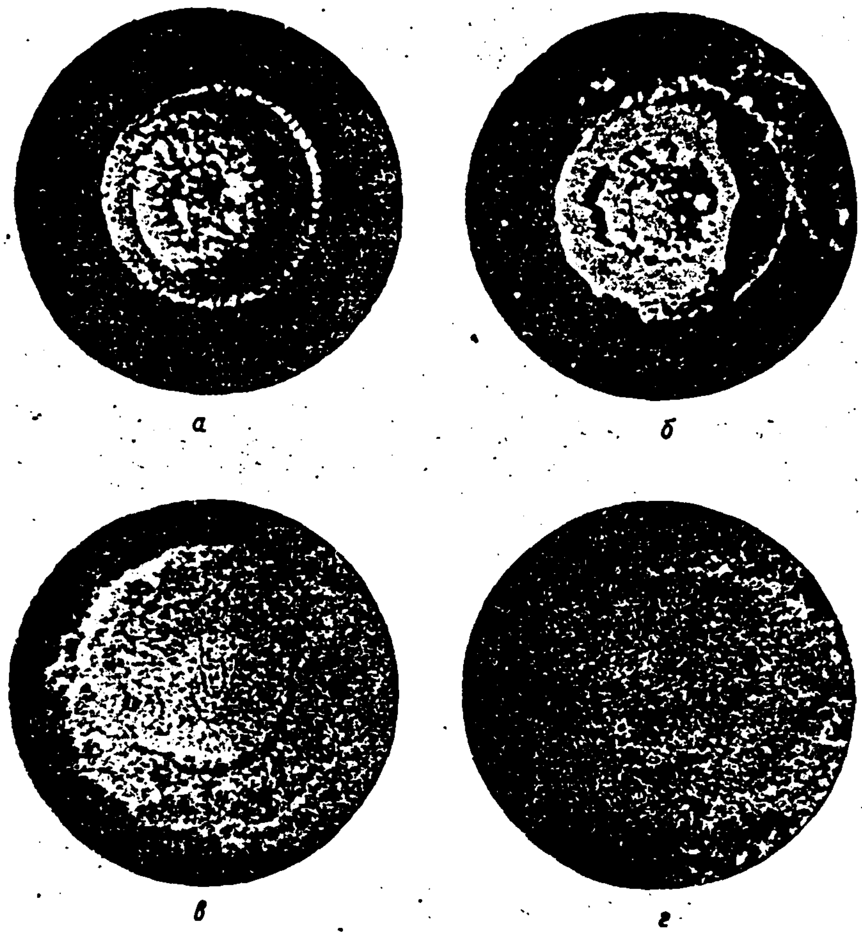

Fig. 8. Damage to a steel ball by a flare from a pointed conical copper electrode after 300 discharges: a - at a distance of 0.3 mm, where the cone served as the cathode; b - at a distance of 0.3 mm, with the cone as anode; c - at a distance of 4 mm, with the cone as anode; d - at a distance of 4 mm, with the cone as cathode.

It is easy to obtain the severe damage to steel objects which is normal for the electric spark method of metal working by means of the copper point of a cone with small spark gaps. Figure 10 shows a photograph of a recess in a file obtained as a result of a few thousand discharges. The dimensions of the damage shown in Fig. 10 are as follows: hole diameter, 5 mm;

depth, 2.5 mm.

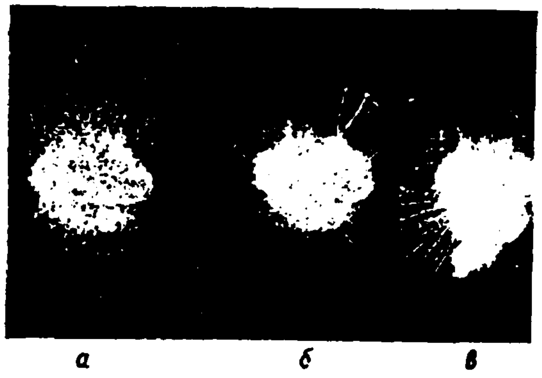

Fig. 9. The discharge between a pointed conical copper electrode and a steel plate: a - first discharge; b - second discharge; c - third discharge. After the first discharge, the luminescence under the plate is noticeable - a plate with a thickness of 0.1 mm is pierced.

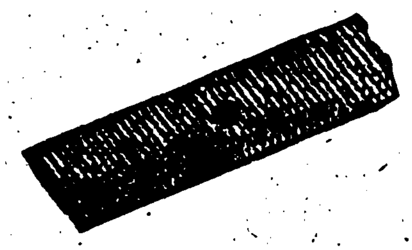

Fig. 10. Photograph of a file in which a hole with a diameter of 5 mm and a depth of 2.5 mm was formed after several thousand discharges.

Screening of Flares

The mechanism of electrical erosion based on the destructive effect of a flare from the opposite electrode should condition elimination of the damage or at least a noticeable decrease in damage in screening of the flare.

Experimental testing of this conclusion was performed by the following method. A round quartz plate with a thickness of 0.5 mm was placed between the electrode subject to destruction - a steel ball - and the flare source - a pointed copper cone (Fig. 11, a). A bevel was made on the edge of the plate. The edge of the plate closed off the conical point of the copper electrode from the ball in projecting above it by 0.1 to 0.2 mm.

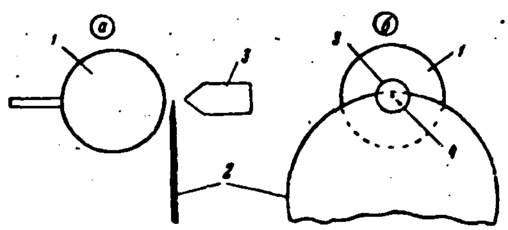

Fig. 11. Diagram of screening of flares: a - a quartz plate 2 with beveled edges is placed between a pointed conical copper electrode 3 and a steel ball 1; b - the projection of the pointed conical copper electrode 3 and the quartz plate 2 on the steel ball 1. The point of the cone is represented as point 4.

A projection of the conical copper electrode 3 and the quartz plate 2 on the ball 1 is shown in Fig. 11, b; 4 is the point of the cone. The plate did not touch the ball or the point of the cone. Under these conditions, one can expect the orientation of the spark channel not to change due to the presence of the quartz plate, while the flares from the point are closed off by the plate to a considerable degree. The experiments demonstrated that damage to the ball proved negligible and was essentially of a surface character. The contour bounding the damaged section of the ball surface precisely follows the contour of the unscreened part of the conical copper electrode (Fig. 12).

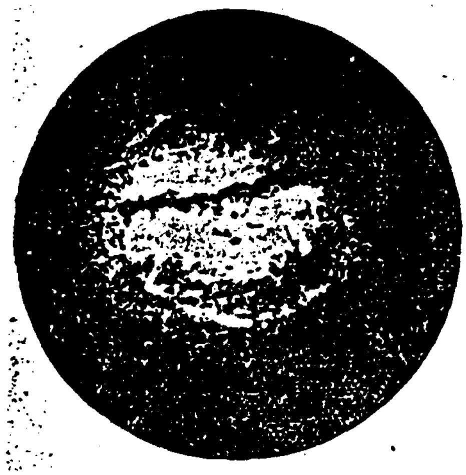

Fig. 12. Damage to a steel ball screened by a quartz plate from the flare from a conical copper electrode. The damage is not great and is noticeable only where the ball was not screened by the quartz plate.

The following experiment was set up for testing. First the number of discharges selected with a screened flare was performed, after which the quartz plate was removed, a new, adjacent section of the ball was placed opposite the point, and the same number of discharges was repeated. Figure 13 shows photographs of the damage of a section of a ball surface in the absence of screening (a) and with screening (b). The number of discharges was 600 in both cases. Screening of the flare thus almost completely eliminates damage to the opposite electrode.

The quartz plate, while protecting the ball against damage, should be subject to the effect of the flare itself. Damage to the plate actually does occur. The damage is so significant that during one of the experiments with screening of the flare, it was

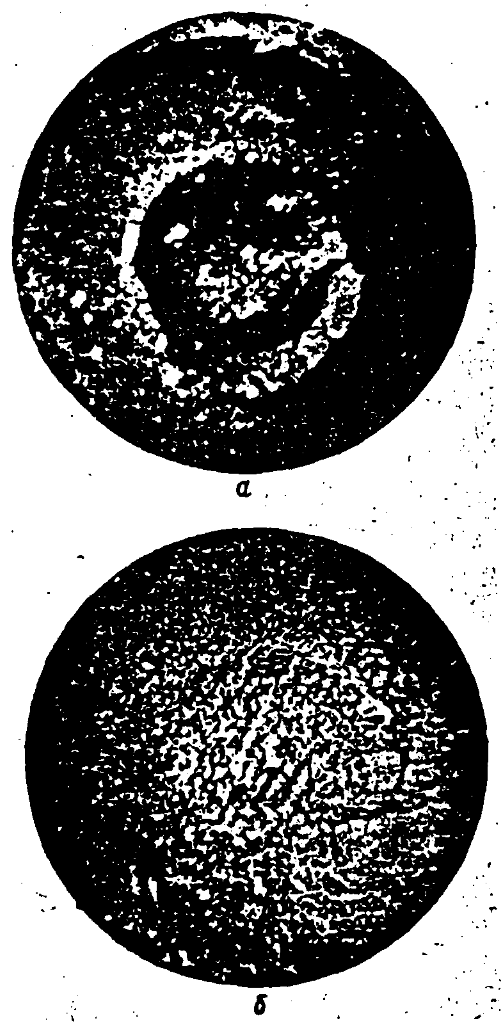

Fig. 13. Damage to a steel ball by the flare from a conical copper electrode: a - without screening of the flare; b - with screening.

Fig. 14. Damage of the edge of a quartz plate which screened flares.

necessary to shift the quartz plate three times to keep the flares from reaching the ball. Figure 14 shows a photograph of a plate on which three sections of its edge damaged by flares can be seen.

The Role of Expansion of the Flares and Experiments with Electrodes Inserted into a Capillary Tube

The rapid decrease in the erosion effect of flares with an increase in the distance between electrodes naturally is explained by expansion of the flares as they move away from the electrodes. In order to prevent expansion of the flares, we artificially limit its diameter by enclosing the cathode, constructed in the form of a wire, in a capillary tube with a diameter of approximately 1 mm made in electrical insulation material. The end of the wire failed to reach the end of the capillary by 3-4 mm; the anode (the flat steel electrode) was located near the end of the capillary. A diagram of the device is given in Fig. 15.

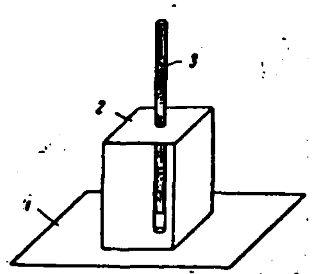

Fig. 15. Diagram of a discharger which prevents expansion of flares: 1 - steel plate anode; 2 - insulator with capillary channel; 3 - copper wire cathode.

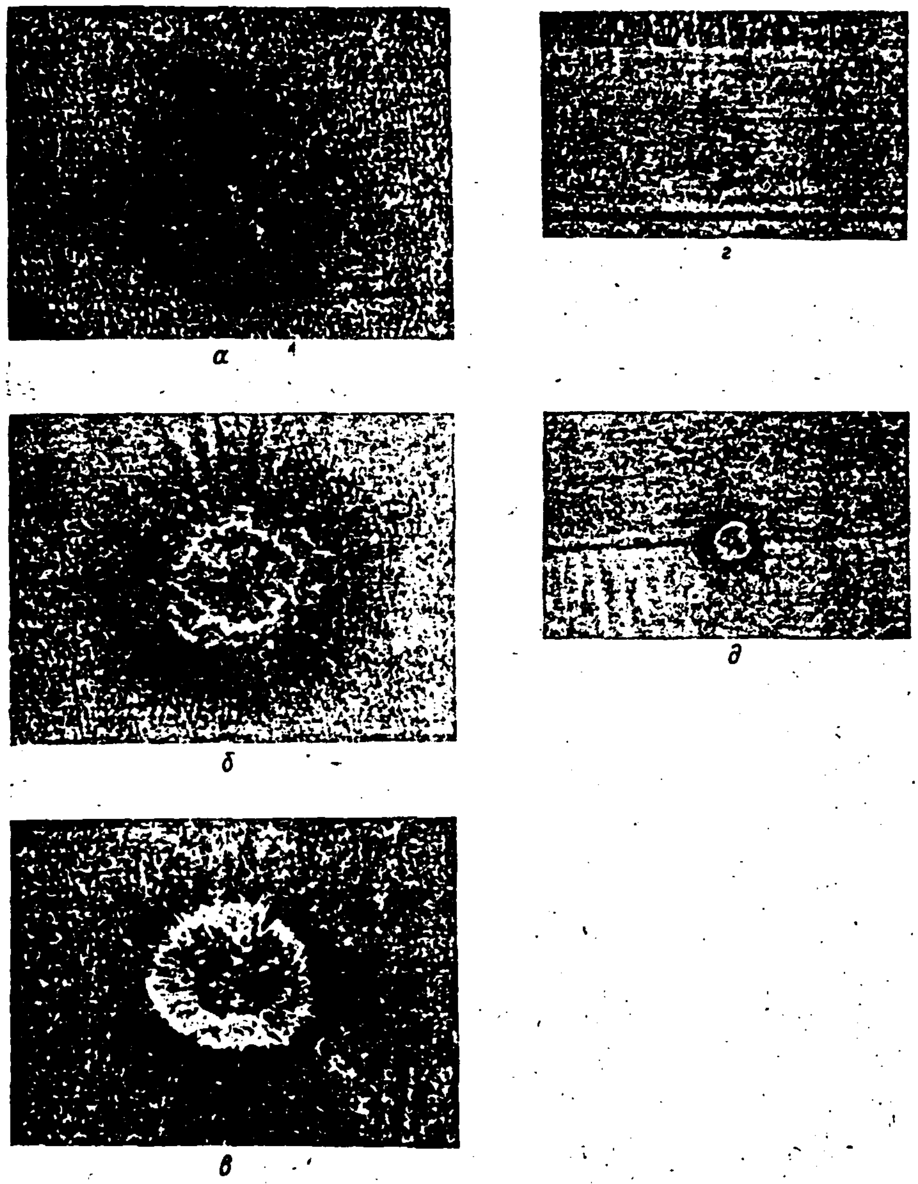

Fig. 16. Damage to a steel plate by a flare escaping from a copper wire cathode placed in a capillary tube; single discharge: a - the plate was located at a distance of 1 mm from the opening of the capillary; b - the plate was located at a distance of 0.5 mm from the opening of the capillary; c - the plate was located at a distance of 0.2 mm from the opening of the capillary; d - damage to a plate by a flare from copper wire not enclosed in a capillary tube at a distance of 1 mm between the plate and the wire; e - damage to a plate by the same flare, but at a distance of 0.2 mm.

Damage of the steel electrode proved just as severe as in experiments without a capillary tube with close positioning of the two electrodes. Figure 16 shows photographs of the damage to a steel plate by a flare escaping from a copper wire cathode enclosed in a capillary tube at different distances between the end of the capillary and the steel plate: a - approximately 1 mm; b - approximately 0.5 mm; c - 0.2-0.3 mm. (We remind the reader that the wire fails to reach the end of the capillary tube by 3-4 mm.)

Photographs of steel plate surfaces damaged by a flare from copper wire directly without a capillary tube at different distances between the wire and the plate are presented in the same figure for comparison: d - 1 mm; e - 0.1-0.3 mm.

Spatial separation of the channel and the flare was effected in the next experiments.

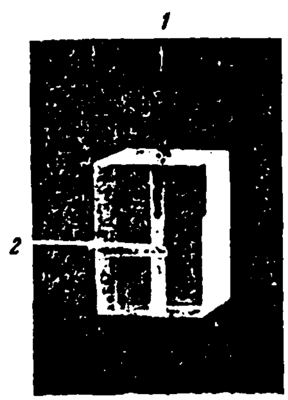

Fig. 17. Discharger in which both electrodes are enclosed in an insulator: 1 - cathode; 2 - anode.

Another wire, the anode (2) (Fig. 17), was inserted into a capillary tube perpendicular to the capillary with the wire which served as the cathode (1). The flare escaping from the capillary tube was aimed at a steel plate. Under these conditions, the flare effected damage to the metal surface placed at the end of the capillary tube of the same severity as in a case where the surface served as an electrode. The flare also had a strong damaging effect on glass, porcelain, etc.

In another version of the experiment, wire electrodes were placed in a capillary tube opposite each other; the discharge products escaped from another capillary drilled perpendicular to the gap between electrodes. The flare escaping from a lateral opening was aimed at the steel plate under investigation. The results of the experiments prove the same as previous results, and the steel plate was extremely severely damaged by the flare.

The form of flares escaping from a capillary tube and possessing a destructive effect is of interest. Their velocities exceed 2 km/s; they are unstable and expand immediately in escape from the capillary.

A photograph of such a flare is presented in Fig. 18, a. This photograph was obtained by the normal method, without limiting the exposure (the flare was photographed from the beginning of its luminescence to ceasing of luminescence). In Fig. 18, b, we present a photograph taken 2.4 μs after the beginning of a discharge with an exposure of 2 μs. This photograph makes it possible to judge the rate of the process of expansion and propagation of the flare and the unique form taken on by the luminescent parts of the flare.

The instability of flares at a high discharge power is an essential feature of the flares and does not depend on random variations of the conditions of an experiment. For example, if flares are released not from one but from several lateral capillaries with some variation of the diameter and the regularity of the surface areas of their side walls, all the flares will have the same form generally, which can be seen, for example, from Fig. 19.

Fig. 18. Photographs of a flare escaping from a capillary tube at different discharge power values: a - at high discharge power values, the flare is unstable; b - a high discharge power values, taken with an exposure of 2 μs; the beginning of the exposure is 2.4 s after breakdown of the spark gap; c - with a decrease in the discharge power, the flare is stable.

Fig. 19. Photograph of 4 flares escaping simultaneously from 4 capillary tubes differing somewhat in diameter and surface preparation in a discharger, with a high discharge power; all the flares are unstable.

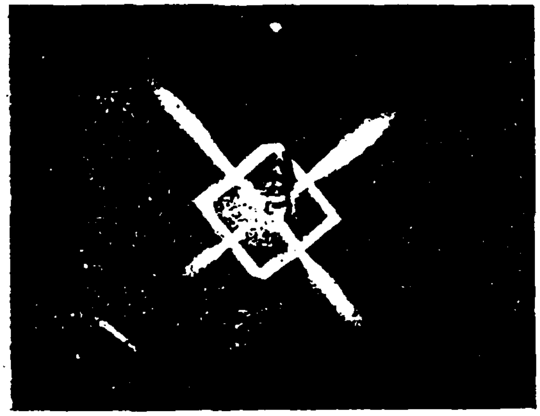

Fig. 20. **Photograph of 4 flares escaping simultaneously from the same capillaries as in Fig. 19 with a decrease in the discharge power; all the flares are stable.**

The flares take on a totally different form with a decrease in the discharge power by introduction of self-inductance: they take on stability and have the form of a smooth, bright jet FIG 18b. And in this case, the form of the flare does not depend on random variations of the experiment, as one can see in Fig. 20, where four flares have been released simultaneously from capillaries differing somewhat in diameter and surface form.

Such smooth and stable flares do not produce an erosion effect.

Intensification of Erosion in
Immersion of Electrodes in a Liquid

We know that in the technology of the electric spark method for metal working, damage to the product being machined increases sharply with immersion of the electrodes in a liquid.

Experiments with an electrode in capillary tubes demonstrated that at a distance between the end of the capillary and the second electrode of the order of 1 mm, when the damage to this electrode in a discharge in air is practically insignificant, a discharge in water produces severe damage.

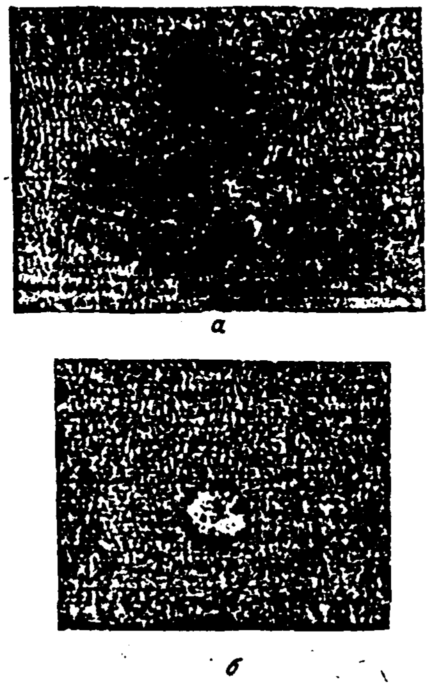

Fig. 21. Damage to a steel plate by a flare: a - in air (the same photograph as in Fig. 16, a); b - in water.

Figure 21 presents two photographs of the damage to a steel plate by a flare with the same spark gap: a - where the electrodes were located in air; b - where the electrodes were located in water.

These experiments demonstrate that the liquid apparently bounds the channel preventing expansion of the flare and intensifying its destructive effect, in a manner similar to a capillary tube.

3. Conclusion

It seems to us that the set of various experiments which we have described above are sufficiently convincing in confirming the hypothesis which has been stated concerning the mechanism of electric spark erosion of metals as a secondary process conditioned by the destructive effect of flares on the opposite electrode.

Movement of the flares at a supercritical velocity apparently is an essential condition for realization of this mechanism. It follows from what has been said that the flares which effect damage expand to the sides immediately after escape from the capillary tube, which attests to the presence of great pressures in the flare. Flares which do not effect damage preserve the form of a jet at a great distance after escape from the capillary, which attests to their subcritical velocity. With respect to the specific mechanism of the destructive effect of flares, this question still has not been explained; the possibility that processes similar to cavitation destruction of metal play a role here has not been excluded. The next significant and as yet unexplained question is that of why damage to the electrode itself is significantly less in intense damage to the opposite electrode. The explanation for this phenomenon apparently lies in the fact that the buildup of an "explosion" on the electrode occurs more slowly than stopping of moving flares by the opposite electrode. Thus in equality of impulses on the two electrodes, the pressure exerted by the flares on their own electrode is less than on the opposing obstacle. The comparatively slow buildup of the "explosion" naturally is explained by the slow current buildup of the spark loop conditioned by a high value of capacitance and by the necessity of heating of a finite mass of "exploding" metal.

It should be mentioned that cases in which the current density in interruption of an arc not shunted by a capacitance, as demonstrated recently by Holm [10], in the first 10^{-6}-10^{-5} s can reach values characteristic of spark modes due to the formation of metal bridges; i.e., more severe damage to the anode than the cathode can occur here as well. This phenomenon apparently is the basis for the electromechanical method for processing metals of V. N. Gusev [11].*

USSR Academy of Sciences P. N. Lebedev Physics Institute

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References

1. Лазаренко Б. Р. и Лазаренко Н. И., Электрическая эрозия металлов.— ТЭИ (ЦБТИ НКЭП), вып. 1, 1944, вып. 2, 1946.
2. Holm R., Electric Contacts.— Stokholm, 1946; Die technische Physik der Elektrischen Kontakte.— Berlin, 1941.
3. Jones, Nature, 157, № 3984, 298 (1946).
4. Абрамсон И. С., Свентицкий Н. С., ЖТФ, 17, 44 (1947).
5. Абрамсон И. С., Гегечкори Н. М., Драбкина С. И. и Мандельштам С. Л., ЖЭТФ, 17, 862 (1947).
6. Соболев Н. Н., ЖЭТФ, 13, 137 (1943).
7. Райский С. М., ЖЭТФ, 10, 531 (1940).
8. Лазаренко Б. Р., Инверсия электрической эрозии металлов и методы борьбы с нарушением электрических контактов. Диссертация.
9. Райский С. М., ЖТФ, 9, 19, 1724 (1939).
10. Holm R., Ark. Mat. Astr. Fys., 34(B), *8*, 1 (1947).
11. Поппилов Л. Я., Завод. лабор., 14, 358 (1948).
12. Somerville S. M. and Blevin W. R., Phys. Rev., 76, *9*, 982 1949).

*Correction: According to the latest data [12], the current density in the first 10^{-5}-10^{-6} s can reach values of 10^5-10^6 A cm^{-2}.

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